Nonlinear Imaging of Topological Edge States in Dielectric Metasurfaces

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Abstract: We fabricate and characterize nonlinear metasurfaces supporting topological edge states at the nanoscale. By employing spectral-selective excitation, we visualize both bulk photonic modes and propagating topological edge states via third-harmonic imaging. © 2019 The Author(s)
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1. Introduction

Topological photonics has emerged recently as a novel approach to achieve the robust routing of light [1]. Since the original demonstration of backscattering-immune photonic topological edge states with the use of a gyrotropic microwave photonic crystal under a strong magnetic field [2], there has been a concerted effort towards realizing topological photonics at the nanoscale. Recently suggested optical designs compatible with non-magnetic all-dielectric structures [3-5] are now coming up as a promising platform for quantum and nonlinear optics applications [5]. The characterization of topological photonic structures becomes more challenging at the nanoscale and typically requires near-field microscopy. Direct imaging of the edge states is essential for assessing the fidelity of the topological waveguides, identifying potential sources of backscattering, and for optimizing the coupling between the edge states and localized emitters.

Here we demonstrate nonlinear imaging of topological edge states in all-dielectric topological metasurfaces by employing the third-harmonic spectroscopy to topological nonlinear metasurfaces. We observe pseudospin-momentum locking of photonic edge modes at the topological interfaces, which can travel around sharp bends without backscattering

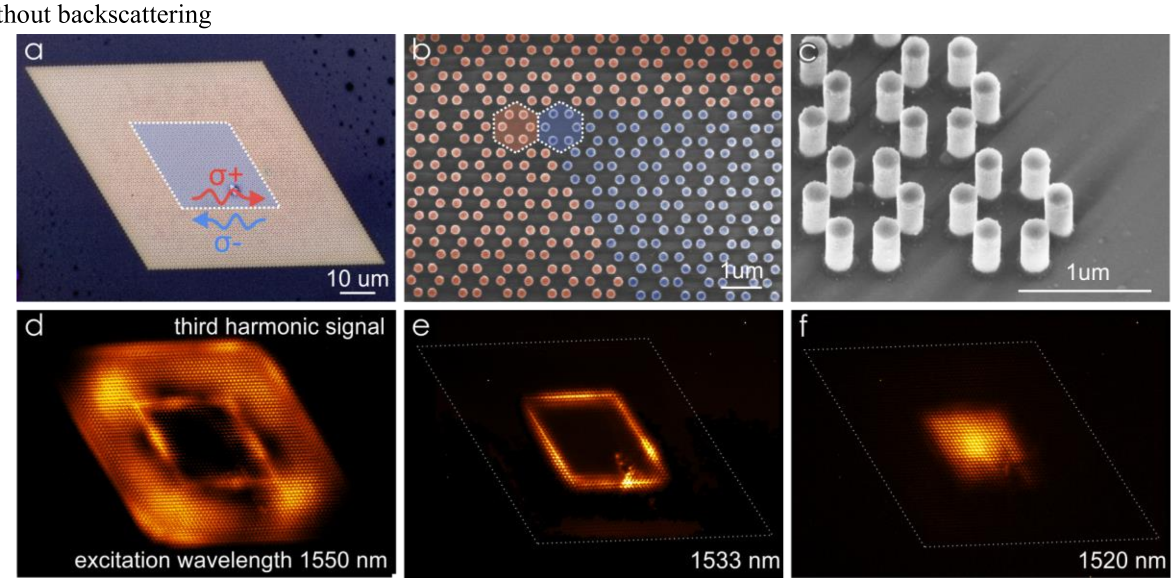

Fig. 1. (a) Optical microscope image of a topological metasurface guiding robust edge waves with the opposite helicities (σ±) along an interface between topologically dissimilar domains. (b, c) Scanning electron microscopy images: (b) top view and (c) side view of the topological metasurface consisting of silicon pillars arranged into hexagon clusters. (b) Domain wall between expanded (blue) and shrunken (red) domains. Framed hexagons highlight corresponding unit cells. Radius of a pillar is r = 105 nm, height h = 538 nm, lattice constant of hexagon clusters a = 1100 nm, shrink/expand coefficients are 0.95 and 1.05, correspondingly. (d-f) Experimental images of the third-harmonic intensity distribution for three excitation wavelengths.

2. Results and Discussions

We fabricate the topological metasurface from silicon on a glass substrate [see the images in Figs. 1(a-c)]. The nontrivial topological properties are achieved by deforming a honeycomb lattice of silicon pillars into a triangular lattice of cylinder hexamers [3]. The metasurface is then excited with 300 fs pulses from a tunable laser system, and the third-harmonic signal is imaged onto a camera. By varying the frequency and polarization of a pump beam and measuring the generated third-harmonic signal, we are able to image selectively either bulk states or spin-momentum locked edge modes, as shown in Figs. 1(d-f).

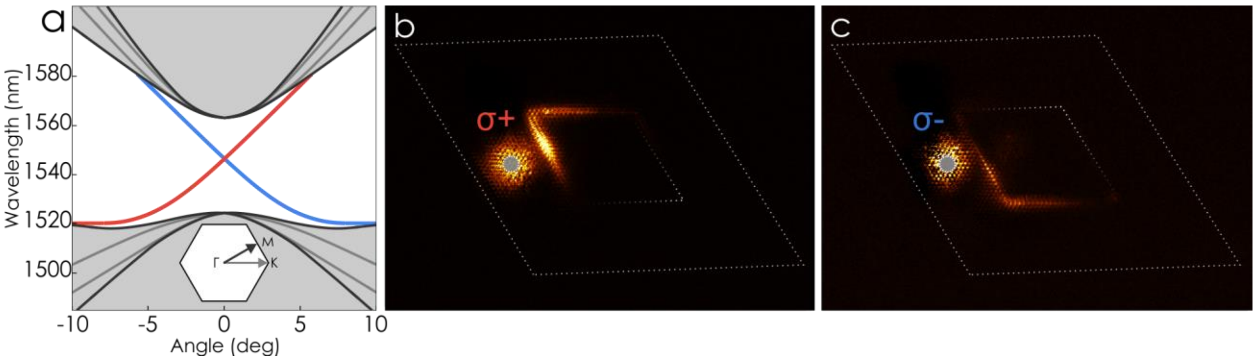

Fig. 2. (a) Numerically calculated photonic band structures for the four doublet bands along Γ-M (black curves) and Γ-K (dark grey curves) directions, found almost perfectly overlaid for shrunken and expanded arrays. The bulk bands are shaded in light grey, while the dispersion branches of the edge modes spanning the topological band gap are shown by coloured curves. Inset: Brillouin zone. (b,c) Spin-momentum-locked topological guided modes. Experimental images of the third-harmonic intensity distribution for the pump focused within the dashed circle with (b) left-circular, and (c) right-circular polarizations.

Figure 2(a) presents the numerically computed bulk band diagram of the structure and the characteristic Dirac-like dispersion of the spin-momentum locked edge states residing in the band gap, which can be selectively excited using a circularly polarized pump beam. We experimentally measure the dispersion of the edge states by tilting the sample and tracing the maxima of the TH spectra independently for the bulk modes and the edge states, the spectral separation of the σ+ and σ- states as the angle increases with the dispersion being close to linear, indicating the edge states are gapless and decoupled, consistent with their topological origin. Next, we study the spin-momentum-locked waveguiding of the optical edge modes associated with the analogue of the quantum spin Hall effect for light [6]. We locally focus the circularly polarized pump beam in a spot near the domain wall [see the dashed circle in Figs. 2(b,c)]. In Fig. 2(b) the pump with σ+ polarization couples to the mode propagating clockwise, while in Fig. 2(c) the σ− pump launches the counter-clockwise wave propagation. Both waves propagate along the domain wall passing the corners.

3. Conclusion

We have suggested a novel approach to visualize topological edge states at optical frequencies by nonlinear imaging, also enabling characterization and optimization of subwavelength waveguides with topological protection for photonic applications. We believe our results make a step towards active photonic devices for the integrated and robust generation and transport of topologically-protected photons in topological metasurfaces.

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4. References

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